

Historical Data for the Secular Acceleration of the Moon.

By J. K. Fotheringham.

Father Kugler, in his recent volume on Babylonian Astronomy,* compares the new moon longitudes given in the lunar tables of Bania and Marduk-tabik-ziru constructed in -102 with the longitudes computed by means of Oppolzer's tables, and concludes that Oppolzer's new moon longitudes are on an average $1^{\circ} 2'$ too high. The accuracy of the constants employed by Bania and Marduk-tabik-ziru is so great, and the observations on which these tables were based were presumably so nearly contemporary, that Father Kugler infers that at least the greater part of the error must lie in the modern, and not in the Babylonian tables. Now, it is incredible that any error approaching this can exist in our modern tables, whose substantial accuracy is confirmed by numerous ancient eclipses, and I have therefore thought it worth while to make a fuller analysis of the tables of Bania and Marduk-tabik-ziru, especially as these, if accurate, ought to furnish us with corrections not only to the Moon's longitude, but to her perigee and node, as also to the longitude and perigee of the Sun.

The most important part of these tables will be found in Father Kugler's *Babylonische Mondrechnung* (1900), pp. 12, 13, where they are accompanied by a very full discussion. The tables are dated at Sippara, -102 December 22, and extend from -103 March 22 to -100 April 17. The lunar constants are, as Father Kugler has shown, identical with those used by Hipparchus, but the Babylonian solar constants appear to be less accurate than those of the Greek astronomer. Father Kugler has computed the sidereal, synodical, anomalistic, and nodical months, and also the sidereal and anomalistic years, by means of these tables, and compares the result with their values in 1800.0, but he has not computed any places except the longitudes of new moon. I have preferred to deduce from these tables the centennial motions and mean places at the epoch -101 December 20.0, G.M.T., exactly 1900 years before the epoch of Hansen's tables, and to compute the secular accelerations which result from the comparison of these with the centennial motions and mean places deduced by Mr. Cowell from modern observations, and published in *Monthly Notices*, lxx. p. 863. As the Babylonian mean motions are sidereal, I have subjected Mr. Cowell's centennial motions to a correction for precession, and in computing the Babylonian places I have provisionally accepted Father Kugler's value for the longitude of the Babylonian first point of Aries. This, reduced to the epoch

* *Sternkunde und Sterndienst in Babel*, i. Buch, *Babylonische Planetenkunde* (Münster, 1907), pp. 172, 173.

that I have used, works out at $355^{\circ} 40' 5''$. I thus obtain the following results:—

Bania and Marduk-tabik-ziru. Epoch - 101 December 20 ^o .					Cowell. Epoch 1800 ^o 0.				
$g = 297$	47	$36 + 171791$	$4714'72$	T	110°	$19'$	$38 + 171791$	5794	T
$\omega = 248$	38	$43 + 2161$	$2559'25$	T	192	7	$25 + 2161$	1516	T
$\Omega = 57$	2	$42 - 696$	$8034'05$	T	33	16	$21 - 696$	7944	T
$L' = 264$	10	$43 + 12959$	$6618'76$	T	279	54	$29 + 12959$	7743	T
$\pi' = 255$	30	$41 + 2980'18$		T	279	29	$47 + 1163$		T

By comparing these two sets of values, I obtain—

Secular Acceleration resulting from B. and M.'s Places.		Secular Acceleration resulting from B. and M.'s Mean Motions.	
g	$= + 52'5 \text{ T}^2$		$+ 28'4 \text{ T}^2$
ω	$= - 26'9 \text{ T}^2$		$- 27'5 \text{ T}^2$
Ω (sidereal)	$= - 50'7 \text{ T}^2$		$+ 2'4 \text{ T}^2$
L' (sidereal)	$= - 12'4 \text{ T}^2$		$+ 29'6 \text{ T}^2$
π' (sidereal)	$= + 87'5 \text{ T}^2$		$- 47'8 \text{ T}^2$

It will be observed that, of the places, all except g yield absolutely impossible secular accelerations, while of the mean motions $g + \omega$ alone yields a possible acceleration. It is highly improbable that the Babylonian astronomers could accurately determine the mean anomaly of the Moon, and not the other elements in its position; and the accuracy of the mean anomaly must therefore be regarded as accidental. The tables are surprisingly accurate, considering the conditions under which ancient observations were made and the difficulties attending lunar theories; but they are useless for the purpose of correcting modern values.

This is the only attempt that Father Kugler makes to deal with secular acceleration. There is, however, a certain amount of material in his recent volume which might conceivably be used for the purpose. Thus on p. 24 he quotes a Babylonian observation of a lunar eclipse, followed at an interval of 14 days by a solar eclipse. The record runs as follows: "In the year 175, Adar II., on the night of the 15th (-135 March 31) an eclipse of the moon on the south-east side of seven digits magnitude took place . . . on the 29th (-135 April 14) an eclipse of the sun on the south-west side." I have not computed the lunar eclipse, to which Professor Ginzel's tables assign a magnitude of 8.8. It adds one to the list of ancient eclipses with definitely recorded magnitudes. The solar eclipse was total at Babylon, according to Professor Ginzel's tables. I have computed it with Mr. Cowell's values, and find an eclipse of the north limb with a magnitude of 10.61. If the description implied that the eclipse was on the south limb it would be fatal to Mr. Cowell's values, but, as the eclipse is at the ascending node, the uneclipsed portion of the Sun

must have been either on the north-west or on the south-east, and the statement that the eclipse was on the south-west side must, apparently, refer to the beginning, and not to the greatest phase of the eclipse. If so, it would be satisfied by any possible combination of lunar and solar values, and is useless for the correction of secular acceleration.

Father Kugler also publishes several tablets giving observed places of the Moon and planets. I have not tested these, and am not prepared to say whether they are sufficiently accurate to be of use for the correction of modern values.

Passing from Babylonian to Greek and Roman data, I have made a statistical account of recorded solar eclipses, classifying them according as they are total, annular, or annular-total on the Earth generally, and according as they are or are not clearly stated or implied to be partial in the records. I only include those eclipses which have been identified with a high degree of probability, and I take them entirely from Professor Ginzel's *Spezieller Kanon*, with the exception of the eclipse of -462 , which I have discussed in *The Observatory* (November 1908, pp. 399-402). They thus represent the eclipses recorded by Greek and Latin writers before 600 A.D. I find that of the recorded eclipses, sixteen (-430 , -423 , -403 , -393 , -93 , -30 , $+186$, $+218$, $+316$, $+324$ or 326 , $+334$, $+360$, $+464$, $+497$, $+563$, $+590$) were annular; thirty-one (-647 , -584 , -462 , -399 , -363 , -309 , -216 , -189 , -187 , -35 , $+29$, $+45$, $+59$, $+240$, $+292$, $+319$, $+346$, $+348$, $+364$, $+393$, $+402$, $+418$, $+447$, $+458$, $+484$, $+495$, $+512$, $+538$, $+540$, $+547$, $+592$) were total; and four (-202 , -103 , $+5$, $+71$) were annular-total. Now there should, on an average, be 13 total to every 16 annular eclipses. We have therefore an excess of 18 total eclipses, which is most easily explained by the supposition that the majority of the total eclipses locally attained a magnitude greater than that of an annular eclipse. This presumption is rendered the stronger when we observe that of the 16 annular eclipses six (-430 , -423 , -393 , $+464$, $+563$, $+590$) are described in the records as partial. The same applies to two (-202 , $+5$) of the four annular-total eclipses, but to not more than three (-216 , $+458$, $+495$) of the 31 total eclipses. Now there is no reason why, among eclipses locally partial, a much larger proportion of those annular on the Earth generally than of those total on the Earth generally should be recorded as partial. The only reason that I can see why the partial character of the annular and annular-total eclipses should have been more frequently mentioned than that of the total eclipses is, that a very large proportion of the latter were locally as well as generally total. It may therefore be inferred that a set of lunar and solar values must not only satisfy the eclipses recorded as total at particular places, but a large proportion of other eclipses. Professor Ginzel's values, which are not based on any eclipses in this list except those of -584 , -309 , $+29$, $+71$, render the following additional eclipses total at the supposed

places of observation: - 647, - 584, - 399 (after sunset), + 393, + 447, + 484; they also assign to the following total eclipses a local magnitude of 11 digits or more: - 462, - 187, + 292, + 418, + 512, + 540. Among the annular eclipses + 590 attains the same magnitude. We thus have 15 or 16 total eclipses, 1 annular-total, and 1 annular eclipse exceeding 11 digits magnitude at the place of observation. This is not far short of the proportion that might be expected. It would be interesting to see whether Mr. Cowell's values, which have yielded more satisfactory results in the cases to which they have been applied, would give as large a proportion of total or nearly total eclipses. The eclipses which cannot be localised and those to which Professor Ginzel assigns a magnitude of less than 10 digits might be omitted. This leaves the following eclipses, to which Mr. Cowell's values have not yet been applied:—

Date.	Probable Place of Observation.
- 393	Chæronea.
- 189	Rome.
- 187	Rome.
- 30	Rome.
+ 29	Nicæa.
+ 59	Rome and Baïæ (?).
+ 71 (immediately after noon)	Chæronea.
+ 186	Rome.
+ 218	Rome.
+ 292	Rome.
+ 319	Rome.
+ 334	Sicily.
+ 346 (stars seen)	Constantinople.
+ 393	Constantinople. Ravenna (?).
+ 402	Ravenna.
+ 418 (stars seen and perhaps corona)	Constantinople.
+ 447	Chiaves.
+ 484 (total)	Athens.
+ 512	Constantinople.
+ 540	Constantinople (?).
+ 590	Constantinople.

In the case of the eclipse of + 364, otherwise unimportant, the exact time of the beginning, middle, and end of the eclipse is given us.

I append a computation which I have made of the eclipse of - 462 with Mr. Cowell's values and formulæ. Mr. Cowell has kindly checked my computation.